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ANTENNA CONNECTION AND SWITCHING FOR TRANSMIT AND RECEIVE DIVERSITY

This application claims the priority under 35 U.S.C. § 119(e)(1) of copending U.S. provisional application number 60/301,402, filed on June 27, 2001 and copending U.S. provisional application number 60/344,896, filed on December 31, 2001. The aforementioned patent applications are incorporated herein by reference.

FIELD OF THE INVENTION

The invention relates generally to wireless communication systems and, more particularly, to an antenna to radio connection and switching for transit and receive diversity.

BACKGROUND OF THE INVENTION

Transmission properties, such as gain and phase, of wireless communication channels are time-varying statistical quantities. Therefore, in a wireless communication system characterized by one (1) transmit antenna and one (1) receive antenna, transmission of information can be unreliable because the wireless channel that exists between the two (2) antennae is constantly changing. In digital wireless systems, the degrading effects of statistical channel variations are particularly evident and are manifested as packet errors.

This degradation occurs whether or not there is relative movement between the transmit antenna and the receive antenna because it is still possible for the environment to change. Wireless channels are also rendered unreliable because the signal at the receive antenna is the superposition of many waves that travel paths of different lengths to the receive antenna and add constructively or destructively. When the waves add destructively, deep fades are experienced. When these fades occur, it is difficult to equalize the channel and decode the data correctly.

One of the most effective ways to overcome this degradation in channel reliability is by employing receive diversity (the deployment of multiple receive antennae). In many scenarios, when the receive antennae are spatially separated by more than half a wavelength, the different receive signals are essentially uncorrelated and independent of the other received signals. Therefore, at an instant in time when the signal-to-noise ratio (SNR) at the output of one antenna is low, there is a good chance that the SNR at the output of at least one of the other antennae is high.

There are several well-known diversity reception techniques that either combine the signals from multiple antennae in different ways or periodically sample the signal from each of the receive antennae and then connect the antenna with the strongest signal to the receiver. It has recently been shown that the benefits of diversity reception can also be obtained from diversity transmission, where multiple transmit antennae simultaneously send differently-encoded versions of the same information. Multiple radios are required to employ diversity

transmission. The general case for diversity would then consist of T transmit antennae and R receive antennae.

When N different radios must share N antennae, diversity transmission and/or reception becomes more difficult to implement. This case may be encountered when, for example, N independent wireless communication systems, each using a different modulation scheme (therefore requiring separate radios), must share N common receive antennae due to limitations such as space constraints. For the implementation of receive diversity, it is problematical to determine how to connect the antennae to the radios so that at any time any of the radios may be assigned to any of the antennae without leaving any radio unconnected. An identical problem arises for the implementation of transmit diversity when several communication systems share N common transmit antennae and at least one of the systems implements M-transmit diversity ($M < N$), If, for example, exactly one (1) system implements M-transmit diversity, then a total of $N - M + 1$ simultaneous transmit systems can be supported by N transmit antennae. Periodically, for a finite length of time, the system implementing M-transmit diversity will require that its M radios be simultaneously connected to M antennae. A problem also exists in determining the radio-antennae connection configuration if the M radio-antennae connections are required to be mutable.

It is therefore desirable to provide a solution that permits connection of a plurality of antennae to a plurality of radios (radio front end units) so that at any time any of the radios may be assigned to any of the antennae without leaving any radio unconnected. The present

invention provides this through synchronously controlled switches that enable a controller to arbitrarily assign any of the radios to any of the antennae while keeping every radio connected to an antenna.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and further advantages of the invention may be better understood by referring to the following description in conjunction with the accompanying drawings in which corresponding numerals in the different figures refer to the corresponding parts, in which:

FIGURE 1 illustrates an *N*-radio-to-*N*-antenna switching arrangement with 2*N* switches in accordance with an exemplary embodiment of the present invention;

FIGURE 2 shows a table of simultaneous connections made by FIGURE 1;

FIGURE 3 illustrates a 2-radio-to-2-antenna switching arrangement with four (4) single-pole-double-throw switches in accordance with an exemplary embodiment of the present invention;

FIGURE 4 illustrates a 2-radio-to-2-antenna switching arrangement with four (4) single-pole-double-throw switches in accordance with a further exemplary embodiment of the present invention;

FIGURE 5 illustrates a 3-radio-to-3-antenna switching arrangement with six (6) single-pole-triple-throw switches in accordance with an exemplary embodiment of the present invention;

FIGURE 6 illustrates a 3-radio-to-3-antenna switching arrangement with six (6) single-pole-triple-throw switches in accordance with a further exemplary embodiment of the present invention;

FIGURE 7 shows a table of simultaneous connections made by FIGURE 6;

FIGURE 8 illustrates an N-radio-to-N-antenna switching arrangement with N switches in accordance with an exemplary embodiment of the present invention;

FIGUREs 9A and 9B illustrate N-radio-to-N-antenna switching arrangements with N single-pole-N-throw switches for $N = 2$ and $N = 3$, respectively, in accordance with exemplary embodiments of the present invention; and

FIGUREs 10A and 10B illustrate single-pole-N-throw switches constructed from single-pole-double-throw switches for $N = 3$ and $N = 4$, respectively, in accordance with exemplary embodiments of the present invention.

DETAILED DESCRIPTION

While the making and using of various embodiments of the present invention are discussed herein in terms of specific switches and switch configurations, it should be appreciated that the present invention provides many inventive concepts that can be embodied in a wide variety of contexts. The specific embodiments discussed herein are merely illustrative of specific ways to make and use the invention, and are not meant to limit the scope of the invention.

FIGURE 1 illustrates *N* radio **120** to *N* antenna **130** switching arrangement **100** with 2*N* switches **110** in accordance with an exemplary embodiment of the present invention. The arrangement of FIGURE 1 (and also FIGUREs 2-10B, below) can be implemented as a wireless transmitter system, a wireless receiver system, or a wireless transceiver system, such as an IEEE 802.11 system, a Bluetooth system or a Global System for Mobile Communication (GSM). Switching arrangement **100** does not use power splitters, each of which carries a 3 dB reduction in power delivered to a radio **120** or an antenna **130**. Therefore, switching arrangement **100** minimizes radio frequency (RF) power losses due to the connection and switching. Figure 1 uses exactly 2*N* synchronously controlled single-pole-*N*-throw (SP*N*T) switches **110**. Each SP*N*T switch **110** is connected to a radio (a radio front end unit) **120** and has *N* outgoing contacts **125** that allow connection to *N* distinct antennae **130**. Likewise, each SP*N*T switch **110** connected to an antenna **130** has *N* incoming contacts **135** that allow connection to *N* distinct radios **120**. Since there are exactly

$(N!)^{2N}$ possible ways to connect $2N$ SPNT switches **110**, by synchronously switching switches **110** through N possible states, each radio **120** can be connected to each antenna **130**. FIGURE 2 shows a table of simultaneous connections made by simultaneously switching switches **110**, wherein $x_N \equiv x \bmod N$. Left-hand-side numerals are the radio indices; right-hand-side numerals are the antenna indices. The wiring shown in FIGURE 1 makes the connections according to FIGURE 2, but there are many other wiring configurations that also implement these connections.

In switching arrangement **100**, there are always exactly two (2) switches **110** between a radio **120** and the antenna **130** to which it is connected. Since each switch **110** has an associated insertion loss, switching arrangement **100** minimizes the number of switches **110** in the path between a radio **120** and the antenna **130** to which it is connected. Switching arrangement **100** also avoids leaving any radio **120** or antenna **130** unconnected or unterminated. Control of the switching can reside with a single antenna master controller **140** which could be a microprocessor that controls switches **110** to make the desired radio **120** to antenna **130** connections. Antenna master controller **140** can assign any antenna **130** to a particular radio **120**, and then simultaneously assign the remaining radios **120** to respective ones of the remaining antennae **130** depending on which of the $(N!)^{2N}$ wiring configurations is implemented and which radio **120** to antenna **130** assignment has already been made by the antenna master.

For any one of the N switching states of FIGURE 2, all switches **110** of FIGURE 1 are in the same position, and each of the N switching states dictates a different (common) position for switches **110**. That is, switching state 1 requires all switches **110** to be in position 1, switching state 2 requires all switches **110** to be in position 2, etc., where position 1 corresponds to the top contact of the switch, position 2 corresponds to the contact immediately below the top contact, etc. This makes it particularly easy to control switches **110** since each switch **110** is controlled to the same position at any given time. For $N = 2$, there are sixteen (16) possible ways to wire the four (4) SP2T switches **110**. One way, consistent with FIGUREs 1 and 2, is shown in FIGURE 3 which illustrates two-radio **120** to two-antenna **130** switching arrangement **300** with four (4) single-pole-double-throw switches **110** in accordance with an exemplary embodiment of the present invention. Each SP2T switch **110** is connected to a radio **120** and has two (2) outgoing contacts **125** that allow connection to two (2) distinct antennae **130**. Likewise, each SP2T switch **110** connected to an antenna **130** has two (2) incoming contacts **135**. Switches **110** are shown in one of two (2) possible switching states, that which implements the first row (switching state 1) of FIGURE 2. The other possible switching state implements the last row (switching state N, for $N = 2$) of FIGURE 2.

Another way to connect switches **110** for $N = 2$ is shown in FIGURE 4 which illustrates two-radio **120** to two-antenna **130** switching arrangement **400** with four (4) single-pole-double-throw switches **110** in accordance with an exemplary embodiment of the present

invention. This configuration also implements FIGURE 2, but the set of states of individual switches **110** which makes a specific radio **120** to antenna **130** connection is different from that of FIGURE 3. Specifically, the four (4) switches **110** are never all in the same position for either of the two (2) possible switching states (i.e., radio1 ⇔ antenna1 and radio2 ⇔ antenna2 or radio1 ⇔ antenna2 and radio2 ⇔ antenna1). Therefore, in this configuration, switches **110** cannot all be driven by the same control signal unless the default state of switches **110** are different.

For $N = 3$, there are 46,656 possible ways to wire the six (6) SP3T switches. One way, consistent with FIGUREs 1 and 2, is shown in FIGURE 5 which illustrates three-radio **120** to three-antenna **130** switching arrangement **500** with six (6) single-pole-triple-throw switches **110** in accordance with an exemplary embodiment of the present invention. Each SP3T switch **110** is connected to a radio **120** and has three (3) outgoing contacts **125** that allow connection to three (3) distinct antennae **130**. Likewise, each SP3T switch **110** connected to an antenna **130** has three (3) incoming contacts **135**. Switches **110** are shown in one of three (3) possible switching states, that which implements the first row of FIGURE 2. The other two (2) possible switching states implement the last two (2) rows, respectively, of FIGURE 2 (for $N = 3$ and $j = 2$).

Another way to connect switches **110** for $N = 3$ is shown in FIGURE 6 which illustrates three-radio **120** to three-antenna **130** switching arrangement **600** with six (6) single-pole-triple-throw switches **110** in accordance with an exemplary embodiment of the

present invention. For this case, the set of switching states is different from those listed in FIGURE 2 and is given, instead, by FIGURE 7. It can be seen from FIGURE 7 that, for the wiring connections depicted in FIGURE 6, any radio **120** can still be assigned to any antenna **130**. Number sequence **610** shown above each switch **110** gives the sequence of positions (where 1 represents the top contact, 2 represents the middle contact and 3 represents the bottom contact) through which that particular switch **110** must progress in order to implement the connections in FIGURE 7. It can thus be observed from FIGURE 6 that individual SP3T switches **110** are never all in the same state and therefore cannot be driven by the same control signal. As is the case for FIGURE 1, switching arrangement **600** allows all switches **110** to change positions at the same time. Sequences **610** of FIGURE 6 can also be seen in FIGURE 7 wherein, for each of the three (3) switching states, the switch positions of switches **110** associated with radio1 (R1), radio2 (R2), radio3 (R3), antenna1 (A1), antenna2 (A2) and antenna3 (A3) are shown in the "Switch Positions" column adjacent to the corresponding reference symbol R1, R2, R3, A1, A2 and A3.

Although FIGURE 1 shows discrete SP*N*T switches **110**, pairs, triplets, quartets, etc. of these SP*N*T switches **110** could be combined (for example, in parallel) into 2P*N*T, 3P*N*T, 4P*N*T, etc. switches **110**, respectively, with *M*P*N*T representing an "*M* pole *N* throw" switch **110**. This would yield an implementation that uses fewer, but more complex, switches **110**.

For the case where the switching circuit is fabricated as stripline or microstrip, and power splitters or power dividers are not used, it is possible to accomplish the general

diversity switching arrangement with only N SPNT switches **110** as shown in FIGURE 8 which illustrates N radio **120** to N antenna **130** switching arrangement **800** with N switches **110** in accordance with an exemplary embodiment of the present invention. In this configuration, there is only one switch **110** in the path between a radio **120** and an antenna **130**. Reflective losses from the $N - 1$ possibly unterminated stubs at each radio **120** connection can be minimized if stub lengths are kept very short compared to the wavelength of the RF carrier. The N radios **120** can be wired to the N switches **110** in $(N!)^N$ ways. FIGUREs 9A and 9B illustrate N radio **120** to N antenna **130** switching arrangements **900A** and **900B**, respectively, with N single-pole-N-throw switches **110** for $N = 2$ and $N = 3$, respectively, in accordance with exemplary embodiments of the present invention. The configurations shown in FIGUREs 9A and 9B implement the connections in FIGURE 2.

The SPNT switches **110** used in switching arrangement **100** can also be implemented as configurations of SP2T switches. The motivation for this is that SP2T switches are very common and allow simple binary control. It can be shown by mathematical induction that an SPNT switch can always be constructed from $N - 1$ SP2T switches. It can also be shown that $N - 1$ is the minimum number of SP2T switches required to construct an SPNT switch. FIGUREs 10A and 10B illustrate single-pole-N-throw switches **1000A** and **1000B**, respectively, constructed from single-pole-double-throw switches for $N = 3$ and $N = 4$, respectively, in accordance with exemplary embodiments of the present invention. However, with SPNT switches constructed from the minimum number of SP2T switches, the number

of switch contacts in the path between the SP*N*T input and one of its *N* outputs is variable. Therefore, the insertion loss will change according to the particular connection made in the SP*N*T switch. For example, there is a minimum of one (1) and a maximum of two (2) SP2T switch contacts in a path in SP3T switch **1000A**, while for SP4T switch **1000B**, there are always exactly two (2) SP2T switch contacts in each path. The minimum and maximum number of switch contacts in these SP*N*T constructions can be easily computed recursively.

Although exemplary embodiments of the present invention have been described in detail, it will be understood by those skilled in the art that various modifications can be made therein without departing from the spirit and scope of the invention as set forth in the appended claims.